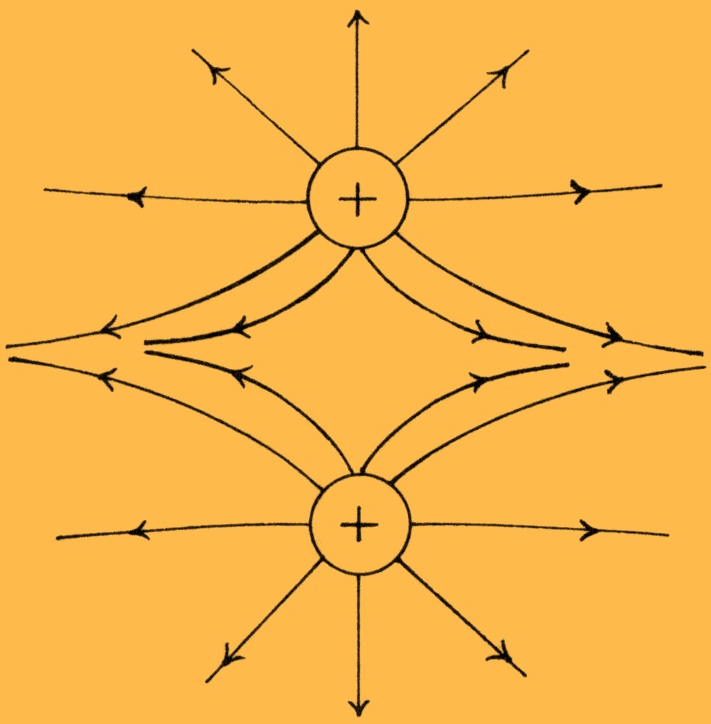
THINGS of science



ELECTROSTATICS

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ELECTROSTATICS

Since the time of the ancient Greeks, it has been known that when a piece of amber is rubbed, small pieces of paper or other light materials are attracted to it. We recognize this phenomenon today as static electricity or electrostatics—electricity at rest.

Through the years, it was observed that objects other than amber also had this property, but it was not until centuries later that any real progress on the subject was made.

In the 16th century, William Gilbert showed that there are two kinds of electricity—the kind that is produced on amber or rubber when they are rubbed with fur and the other on glass when it is rubbed with silk. The two types were first named resinous electricity and vitreous electricity respectively. However, Benjamin Franklin in the 18th century designated them as negative and positive electricity, and this is what they are still called today.

In 1785 Charles Augustin de Coulomb provided a mathematical basis for the behavior of electrically charged bodies, now known as Coulomb's law, and from that time on great advances were made in the study and use of electricity.

All of you more than likely have had some experience with static electricity—

the shock you feel when the door of a car is touched on a cold dry winter's day, the crackling sound heard when a nylon sweater is removed or when a rubber comb is run through the hair. These occurrences are evidences of the existence of electrical charges.

We know such things happen, but why do they?

With the materials in this unit you will be able to observe some of the basic electrostatic phenomena which will help you understand the why of static electricity.

First examine your materials.

GLASS ROD—Five inches long.

STYROFOAM BALLS—Two.

BALLOONS—Two.

WIRES—Two steel wires 5½ inches long.

ALUMINUM FOIL—Fine gauge aluminum sheet; 3 x 5 inches in size.

Cut your aluminum foil into sections as shown in Figure 1 before starting your experiments.

ELECTRIFICATION BY FRICTION

All matter is made up of tiny atoms. According to the atomic theory, each atom composing a substance has a central nucleus containing positively charged protons, and except for hydrogen, also neutrons that have no charge. Revolving around this nucleus are electrons that

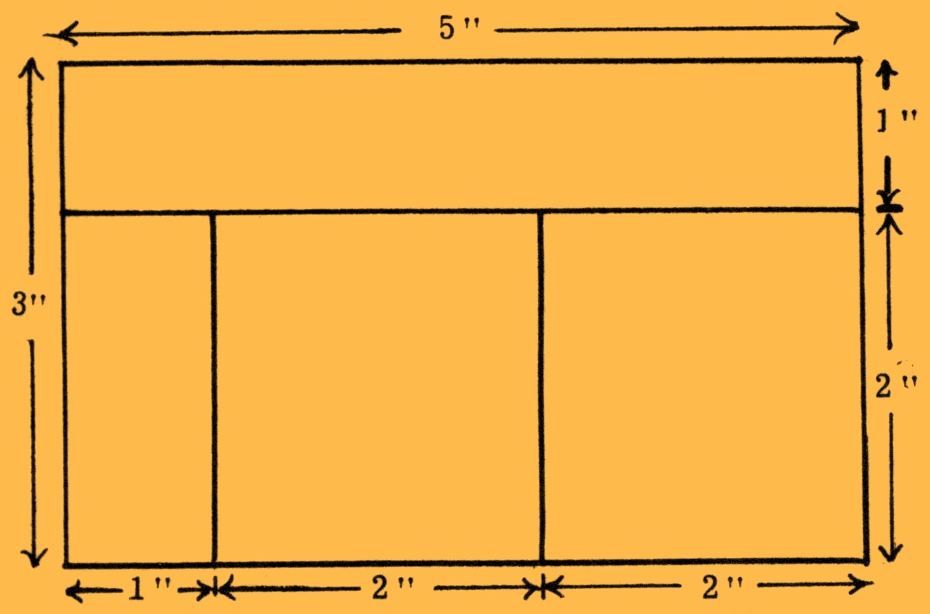


Fig. 1

are negatively charged. Under normal conditions the number of electrons and protons in an atom are equal in number and since the negative and positive charges balance each other, an electrically undisturbed atom is neutral in charge.

The force of attraction between the protons and electrons bind the electrons to the atoms. However, this force decreases with distance and the electrons furthest from the nucleus are held with such little force, they can wander away and move from atom to atom within a substance. These wanderers are referred to as free electrons.

Under certain conditions the atoms will give up some of these free electrons. But not all atoms or groups of atoms give up their electrons with equal ease. The attractive force binding the electrons to

an atom varies from substance to substance.

Rubber, for instance, has a stronger affinity for electrons than does fur. Therefore, when a piece of hard rubber is rubbed against fur, some of the electrons from the fur attach themselves to the rubber. The rubber thus acquires an excess of electrons and becomes negatively charged. The fur, on the other hand, loses electrons becoming positively charged.

With glass the opposite is true. A glass rod will give up electrons when rubbed with silk. It, therefore, becomes deficient in electrons and since the positive protons are now in excess, the glass rod becomes positively charged. The silk having gained electrons becomes negatively charged.

The electrons in each case have simply been transferred from one object to another—there is no loss in total electrical charge.

This process of charging objects by rubbing them against each other is known as electrification by friction.

NOTE: All of the experiments on static electricity will give better results when performed in dry weather. Therefore, if the weather is very humid, wait for a day of lower humidity to do your experiments.

Experiment 1. Tear some fine paper, such as facial tissue, into tiny pieces about ¼-inch in diameter and place

them on a table. Rub the glass rod briskly with a piece of silk material and then bring the rod close to the bits of tissue. Note how they are attracted. Do some pieces cling to the rod? Repeat with ¼-inch lengths of fine thread.

Cut a ⅛-inch-square piece from your 1 x 2-inch strip of aluminum foil. Does the glass rod attract the metal too?

The glass rod positively charged by friction attracts metal as well as paper and thread.

Experiment 2. Blow up one of your rubber balloons to about 4 inches in diameter and tie it securely with thread. Rub the balloon against fur, wool or your hair. Does it also attract the bits of paper and the piece of aluminum?

The balloon became negatively charged by friction. If you have a hard rubber comb charge it by rubbing it against wool and repeat the experiment.

Whether charged negatively or positively, a charged body will attract a neutral body.

What happens?

Early experiments showed that like charges repel and unlike charges attract each other.

Uncharged objects, such as the bits of paper, have an equal number of positive protons and negative electrons. However, when the positively charged glass rod is placed near the paper, a rearrangement

of the charges takes place in the paper. The negative electrons are attracted to the glass rod and move to the end of the paper closest to the glass rod and the positive protons are repelled to the farther end. If the charge in the rod is great enough, the force of attraction will overcome the weight of the paper and lift it to the rod (Fig. 2).

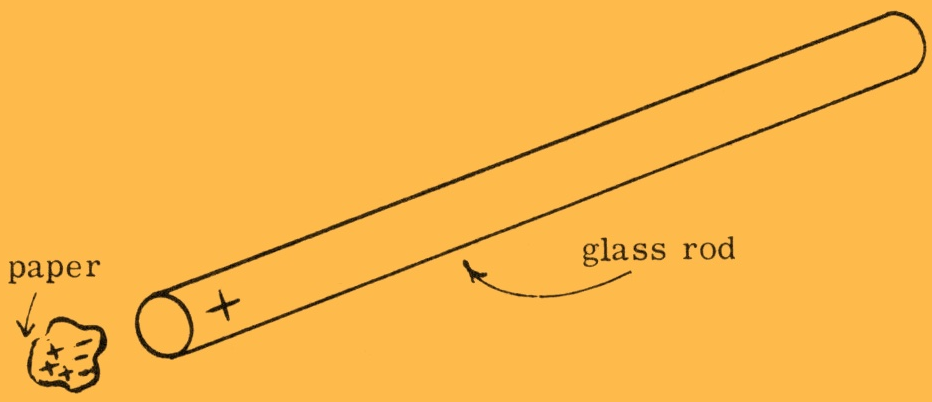


Fig. 2

Any object when rubbed against another will produce an electrical charge, but not every object will retain the charge.

All materials can in general be divided into two classes, conductors and non-conductors or insulators. Conductors are those substances through which an electric charge can readily pass and insulators are those through which electrons cannot flow or flow with difficulty.

Metals, water and certain other liquids such as salts and acids are good con-

ductors, while rubber, glass, wool, silk and plastics are examples of insulators.

Experiment 3. Rub a piece of metal such as a nail, spoon or scissors with silk cloth. Does it attract the bits of paper? Rub it with wool. Does it now attract the paper?

Metal is a conductor and does not exhibit static electricity when held in your hand and rubbed with silk or wool. Our bodies are good conductors of electricity and any electrons that might have been transferred to the metal will flow away from the metal to our bodies. However, if the metal is insulated with a rubber or plastic handle, the electrons cannot escape and will remain on the metal if negatively charged by friction.

Insulate the metal you used and see if you can create static electricity in it now. Test for the charge with the bits of tissue.

Ordinarily static electricity is observed only on nonconductors or insulated substances since the charge must remain on the object. This is why high humidity interferes with experiments on electrostatics. The thin film of moisture that can form on the surface on a humid day is often conductive enough to allow the charge to flow away rapidly.

An electric charge on a glass rod may be quickly dissipated by leakage since glass is a good insulator only under conditions of low humidity. In your experi-

ments leakage from your glass rod may be reduced by wrapping one end of the rod to a depth of about one inch with cellophane tape or by coating the end with shellac and using this end as the handle.

Experiment 4. Cut a strip about 10 inches long and ½-inch wide from a newspaper. Rub your glass rod vigorously on silk material. Then bring the rod close to one end of the paper. Is the paper attracted to it?

Again rub the glass rod with the silk material. This time bring the silk close to the paper. Is it attracted to the silk? Since the glass rod gave up some of its electrons to the silk material, the silk has also become electrified and attracts the paper.

IDENTIFYING THE CHARGE

Experiment 5. An electric charge will remain on a body until it is either grounded by contact with a conductor, neutralized by an oppositely charged body or otherwise dissipated.

We can check to see whether an object is electrified or not by constructing a simple ball pendulum device.

Take a piece of facial tissue about one-inch square and roll it into a ball about ¼-inch in diameter. Wrap it with a piece of your aluminum foil about ½-inch square cut from the 1 x 2-inch section. Now roll it between your palms

to form as perfect a sphere as possible. Be sure the tissue is completely covered. If any tissue is exposed, use another small piece of the foil. The aluminum foil makes the surface conductive. Since electrons can travel about readily in a conductor, the pendulum ball is highly responsive to charged bodies.

Suspend the ball with a 12-inch long fine sewing thread. Silk or nylon thread would be best for this purpose although cotton thread may be used. Thread a fine needle with the thread and tie a small knot at the end. Pass the needle through the exact center of the ball, pulling the thread through gently. Tie the free end of the thread to a coat hanger or other convenient support where the metal ball can hang with at least 12 inches of free space around it.

You now have a pendulum device with which you can test an object to see whether or not it is charged. Be sure the ball remains neutral in charge. You can ground it by touching it.

Rub various articles against wool or silk and see if they attract the ball. In all these tests, do not allow the charged object to come in contact with the ball.

From your previous experiments you know that any charged body will attract a neutral body. These experiments will therefore show you which objects have become electrified. However, the results

will not indicate whether the substance is negatively or positively charged.

In order to identify a charge, we must start with an object with a known charge.

Experiment 6. It is known that when a glass rod is rubbed with silk, it acquires a positive charge and when a rubber object is rubbed with wool, it becomes negatively charged, and that like charges repel and unlike charges attract.

To identify the charges use the pendulum device.

Rub the balloon with wool or fur to charge it negatively. Bring it near the pendulum. Note how strongly the tiny ball is attracted to it. Now touch the ball with the balloon and note how strongly it is immediately repelled. Allow the ball to come to rest. Do not touch it. Now bring the charged balloon toward the pendulum. Is the ball repelled?

When a negatively or positively charged object touches an uncharged substance, the neutral body acquires the same charge as the electrified object. This is known as charging by contact (see page 14). On contact some of the excess electrons from the negatively charged object is transferred to the neutral body and a positively charged object takes up electrons from the neutral body.

Since like charges repel, the ball must now be negatively charged like the balloon (Fig. 3).

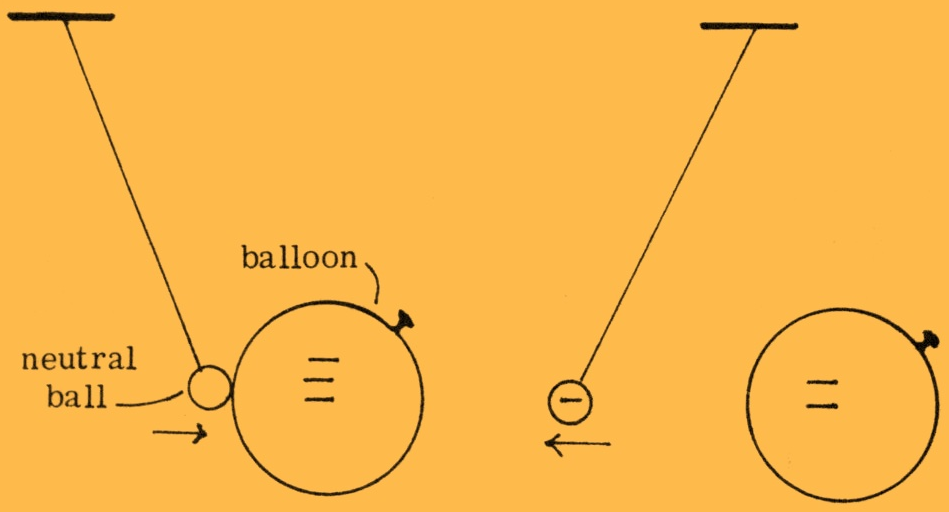


Fig. 3

The excess electrons transferred to the ball by the balloon cannot immediately escape since the thread acts as an insulator and the ball remains negatively charged.

Now that you know the charge on your ball pendulum is negative, you can identify the charge of any other object by bringing it close to the ball.

In the following experiments, do not allow the ball to touch the object being tested.

Experiment 7. Charge the balloon with silk. Does it attract or repel the ball?

Rub the glass rod with silk. Does the glass rod attract or repel the ball? Rub the glass rod with a polyethylene bag. Does it become negatively or positively charged?

Test the charges on other objects electrified by friction, such as newspaper, pieces of rayon or nylon cloth and make

a chart of paired objects that are electrified when rubbed together indicating for each whether it is negatively or positively charged.

You may have to recharge the ball from time to time since the excess electrons will eventually escape.

Experiment 8. Another method to identify an electric charge is to start with your glass rod which becomes positively charged when rubbed with silk.

Make a stirrup for your glass rod with one of the wires in your unit (Fig. 4).

Bend the wire exactly in half and then turn up the ends to form open loops in which the rod can be easily placed. Attach a strong thread to the top of the stirrup and suspend it where it can hang freely. Be sure the rod will lie horizontally in the stirrup so that it will not slip out and break.

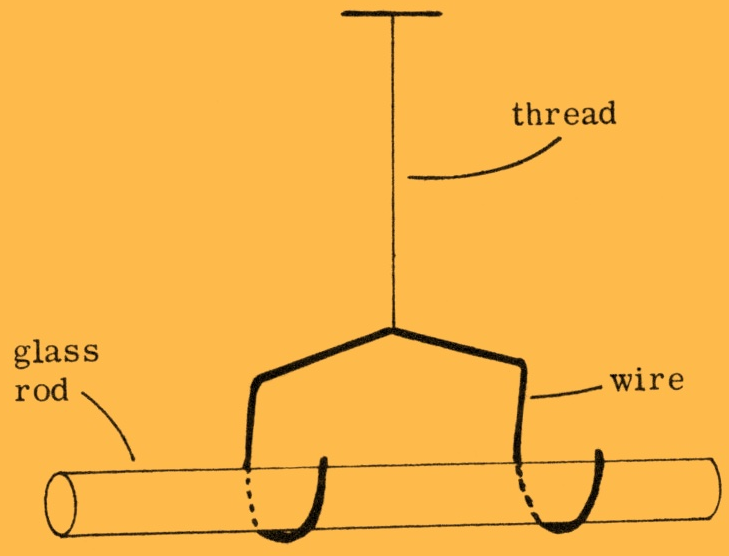


Fig. 4

Charge your glass rod with silk and place it carefully in the stirrup.

Now electrify a small drinking glass or glass jar with the silk cloth. Bring the charged glass close to the rod. Note that the rod moves away from the glass. Since like charges repel each other, the drinking glass must also be positively charged (Fig. 5).

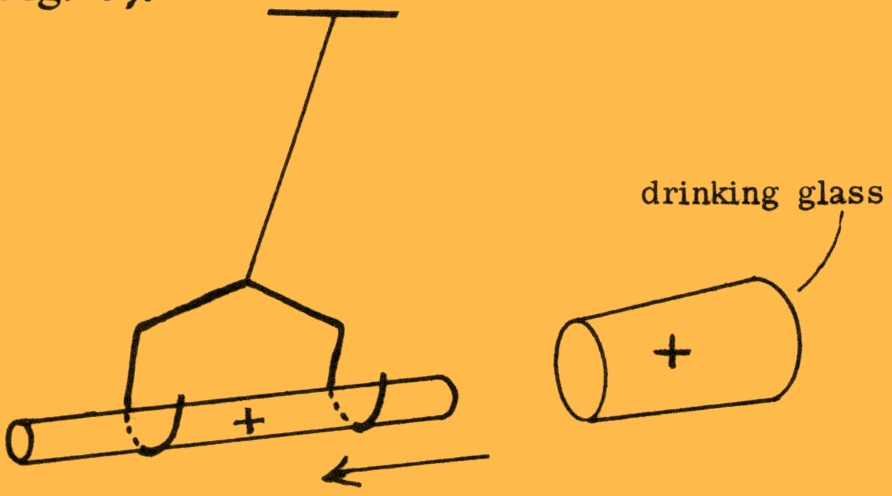


Fig. 5

Rub the drinking glass with a polyethylene sandwich bag. Test its charge with the glass rod. Is the glass rod attracted by the balloon electrified with wool?

Experiment 9. Using the glass rod, retest the various objects you checked in Experiment 7 and confirm your results.

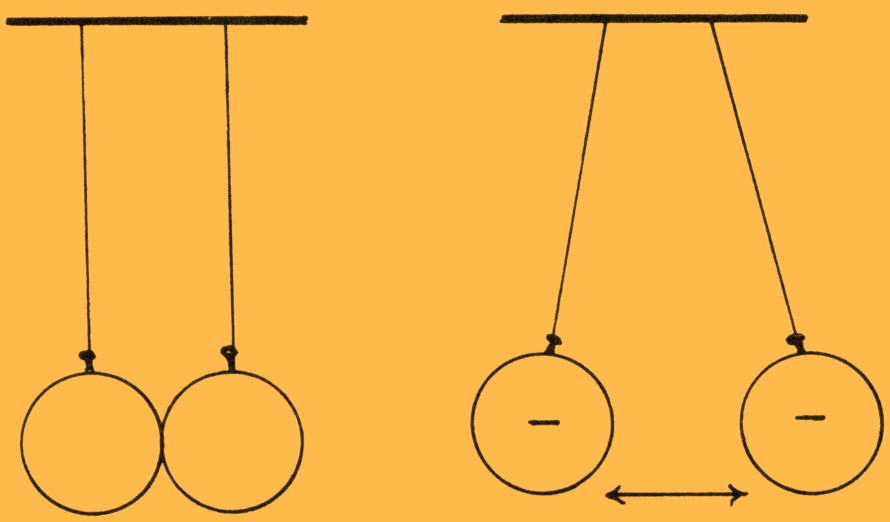
CHARGE BY CONTACT

When two objects, one neutral and the other electrified either positively or negatively come in contact with each other, the free electrons tend to distribute them-

selves evenly between the two seeking a state of equilibrium. Thus a negatively charged object transfers some of its electrons to a neutral body causing it to become negatively electrified and a positively charged body takes up electrons from an uncharged object leaving it also positively electrified.

This transfer of electrons between two objects by touching is referred to as charging by contact. Only the electrons are free to move from object to object. The protons are held tightly in the nucleus.

Experiment 10. Blow up your second balloon to the same size as your first balloon. Suspend the two balloons with a thread about 15 inches long from a coat hanger or other support so that they just barely touch each other (Fig. 6a). If the balloons have acquired a charge



a. neutral balloons b. negatively charged

Fig. 6

while being blown up and handled, allow them to come in contact with a large conducting object and the charge will be gradually dissipated.

When the balloons are neutral an equal number of negative and positive charges are randomly distributed over their surface.

Now charge one of the balloons by rubbing it with wool. Allow it to touch the second balloon. What happens? When the charged balloon touched the uncharged one it shared some its free electrons with it causing it to become negatively charged also. The two balloons therefore now repel each other (Fig. 6b).

Experiment 11. A glass rod, positively charged will take up electrons until it becomes neutral again.

Charge your glass rod with the silk material and bring it close to the negatively charged balloons. Note how they are attracted by the glass rod. Touch the balloons with the glass rod. Now remove the rod. Do the balloons still repel each other? Recharge the glass rod if the balloons still repel each other and touch the balloons again. Repeat as many times as necessary. The negative charge will finally be neutralized when all the excess electrons are removed.

When the balloons are neutral, charge the glass rod with silk and touch the balloons once more. What happens now?

Repeat the process several times if you do not get an immediate result. Do the balloons repel each other? The balloons have become positively charged by contact.

When the glass rod is brought near the balloons again are they repelled by the rod? (Fig. 7)

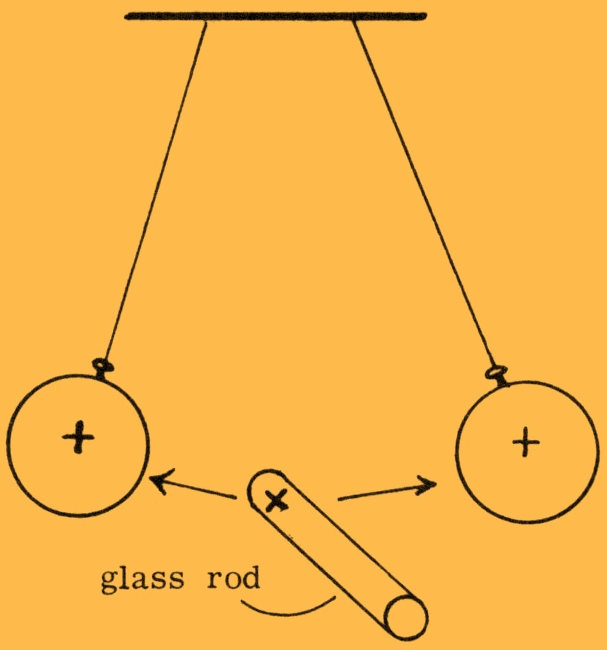


Fig. 7

Experiment 12. Cover your two styrofoam balls with aluminum foil using the two pieces 2 x 2 inches square. Smooth the foil out as much as possible. Suspend the two balls with thread about 12 inches long allowing them to just barely touch each other.

Touch the two balls with a negatively charged balloon. Take the balloon away and the balls will stand away from each

other, both having acquired an excess of electrons. Now touch one of the balls with your finger to ground it. What happens?

The neutral grounded ball is attracted to the charged one and on contact, acquires a negative charge again and the two will repel each other although not as strongly as before (Figs. 8a-e). Why?

Coulomb demonstrated that a field of

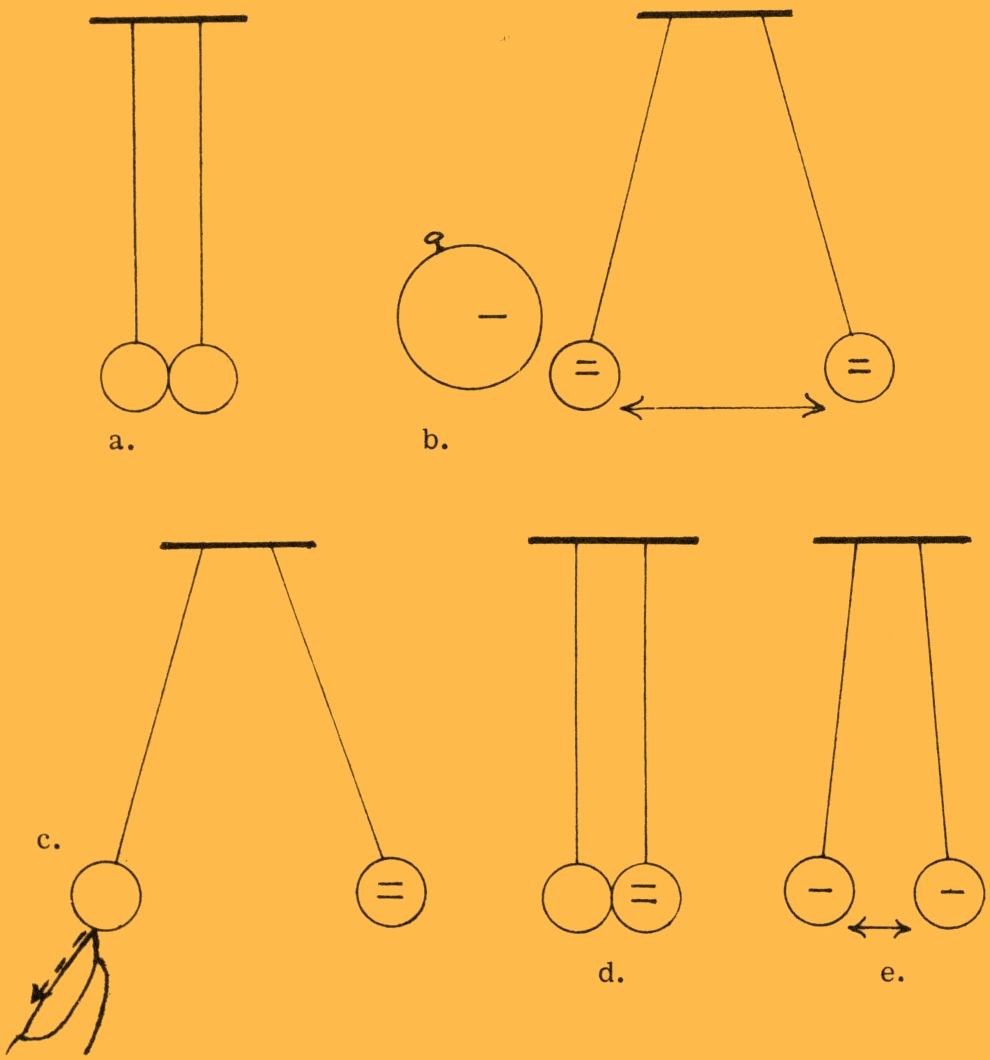


Fig. 8

force exists around an electrically charged body. When an object is electrically charged, a field of force is created within its immediate neighborhood. It is this force that causes like charges to repel and unlike charges to attract. Although the exact nature of this force is still not known, its behavior is defined by Coulomb's law. Coulomb showed by experiments that the force between two charged bodies is related to the amount of charge on each body and the distance between them.

To make it easier to visualize an electric field the field of force is represented by lines of force. On the front cover the lines of force between two positively charged bodies is shown. The arrows indicate the direction of the field.

If the charge on one body is given as q_1 and on the other as q_2, and they are **r** distance apart, the total force exerted by q_1 on q_2 is equal to that exerted by q_2 on q_1 and is inversely proportional to the square of the distance between them. The magnitude of the force is proportional to $\frac{q_1 \, q_2}{r^2}$.

This means that the repellent force we observe between two bodies with like charges is the net force between the two and that the repellent force between them becomes greater as the distance between

them decreases. If the distance is decreased by one-half, the force is increased 4 times ($\frac{1}{2}^2$); decreasing the distance to ¼ makes the force 16 times greater ($\frac{1}{4}^2$). This is true also for the attractive force between unlike charges and is referred to as the inverse square law.

Experiment 13. Neutralize the metal ball of your pendulum by grounding. Rub your balloon once with the woolen cloth to charge it slightly. Touch the ball with the balloon to charge it by contact. Note that when the balloon is again brought near it the ball is repelled slightly.

Now charge the balloon again, this time by rubbing it vigorously on the wool to give it a strong charge. Neutralize the ball and bring the balloon close to it. Notice how strongly it is attracted to the balloon and then how forcefully it is repelled after contact.

The greater the charge, the stronger the attractive and repellent forces.

Experiment 14. Hold the charged balloon about six inches from the charged ball and note that it is repelled slightly. Reduce the distance of the balloon by one-half. Is the ball more strongly repelled? Decrease the distance further. Is the repellent force greater?

As the distance between two bodies with like charges is decreased the repellent force is increased.

Experiment 15. Electrify one of your

balloons with a wool cloth. Bring it near the bottom of a neutral foil-covered styrofoam ball suspended from a stable support. Gradually decrease the distance between the two being careful not to let them come in contact with each other. You will suddenly hear a crackling sound and may see a small flash of light.

As the balloon approaches the ball, the electric forces between them become so great that the air in the space between them becomes conductive and the electrons from the balloon jump across to the ball. The flash of light is due to an electric spark which Benjamin Franklin proved to be the same in nature as lightning with his famous kite experiment, and the crackling sound is the thunder in miniature.

What is the charge of the ball now? Does it repel the balloon? The ball has acquired electrons from the balloon and is now negatively charged.

What would the charge be on the ball if a glass rod rubbed with silk had been used in the experiment instead?

Experiment 16. Neutralize the styrofoam ball. Charge your glass rod with silk. Hold a piece of plastic such as the plastic lid of a coffee can or a sheet of paper between the glass rod and the ball. Is the ball attracted?

Now charge the ball positively with the glass rod by contact. Place the plastic

between the glass rod and ball again. Is the ball repelled? What happens when the glass rod is removed? Is the ball attracted to the plastic? If so, why? (Fig. 9)

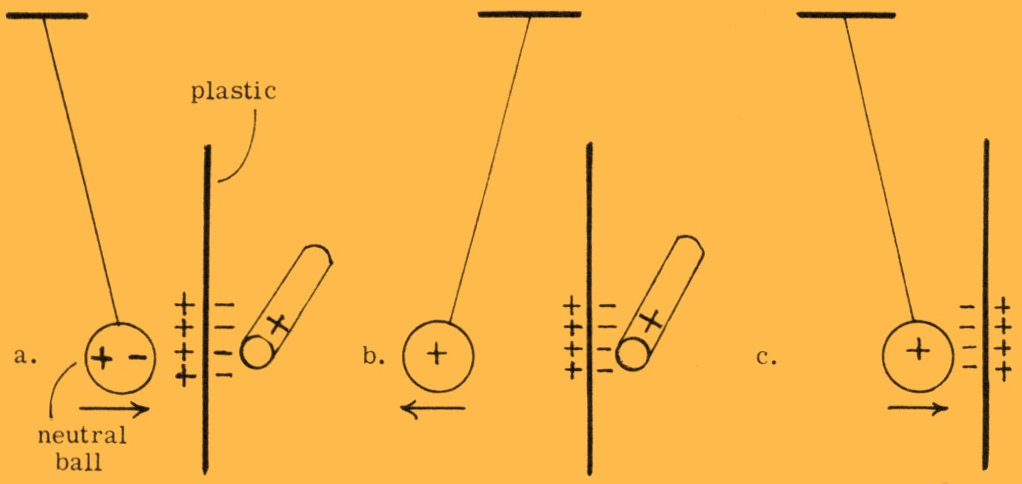


Fig. 9

The field of force is transmitted by a nonconductive material if the charge is great enough.

CHARGE BY INDUCTION

You have observed that in each case when a charged body was brought next to an uncharged body the neutral body was attracted to the charged body, whether negative or positive.

Experiment 17. Using the ball pendulum demonstrate the attraction of a neutral body by both positive and negative bodies (Fig. 10). Why is it always an attraction?

If the balloon or glass rod is not

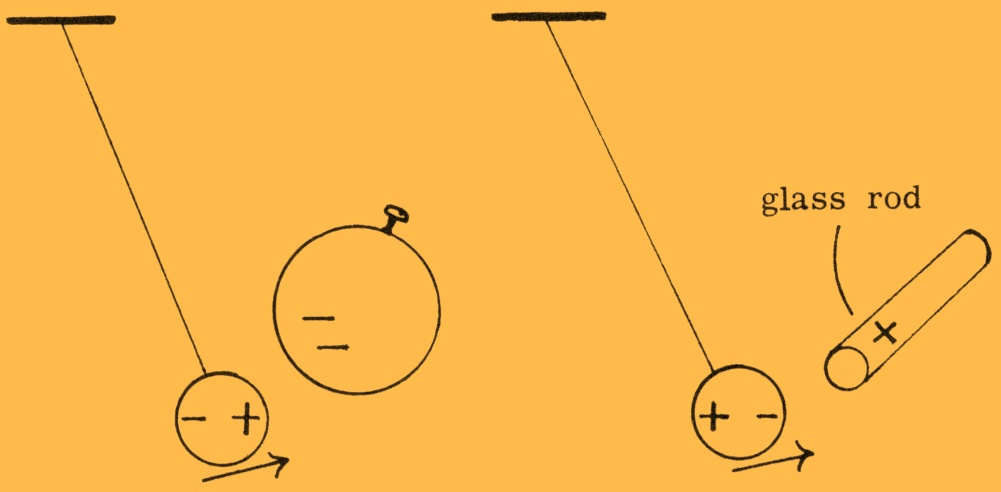


Fig 10

allowed to touch the ball and is removed, the pendulum falls back into its resting position and when tested will show no charge. To show that it has no charge bring an uncharged body near it. It will show no attraction for it.

When the electric field of force is removed, the atoms go back into their original neutral state. Since no contact was made and no charges were lost or gained, the ball remains uncharged. The charges on the ball were only temporarily displaced.

Experiment 18. Charge your balloon again and bring it close to the ball without letting the two come in contact with each other. This can best be done by holding the balloon beneath the ball. While keeping the balloon close to the ball with one hand, touch a finger of your other hand to the ball.

Now withdraw both the charged balloon and your finger.

Electrify your glass rod with silk and bring it toward the ball. Is the ball repelled? What does this result indicate? A charge was imparted to the neutral ball without contact with the charged object. What happened?

The positive charges of the ball were attracted to the negative charges of the balloon and were bound by them, while the electrons were repelled to the opposite side, free to move as far away as they could. The free electrons escaped through your finger to the ground when you touched the ball leaving an excess of positive charges (Fig. 11).

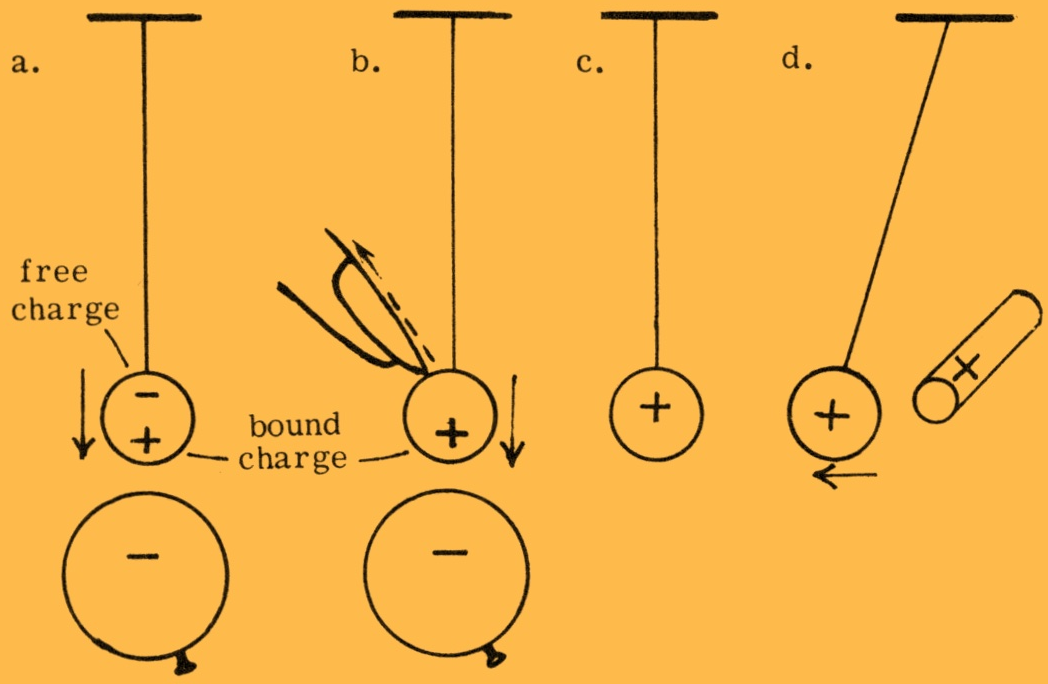


Fig. 11

This is known as charging by induction.

Experiment 19. Take two wooden toothpicks and insert them into the foil-covered styrofoam balls from which the threads have been removed.

Charge your glass rod positively and place it in the wire stirrup.

Now electrify a balloon with woolen cloth.

Using the toothpicks as handles, hold the two balls in contact with each other. Bring the negatively charged balloon close to one ball, but not in contact with it, so that the three, the balloon and the two balls, are along a straight line (Fig. 12a).

While the balloon is still close to the balls, separate the two balls. Bring the ball that was closer to the balloon (ball A) near the glass rod. Does it repel it? Bring the other ball (ball B) near the glass rod. Does it attract it?

What causes these results?

When the balloon was brought near ball A, it repelled the electrons which then traveled to the opposite side of ball B. When the two balls were separated, an excess of electrons remained on ball B while ball A had an excess of protons (Fig. 12b).

Since the glass rod was positively charged it repelled ball A and attracted ball B.

This experiment demonstrates that

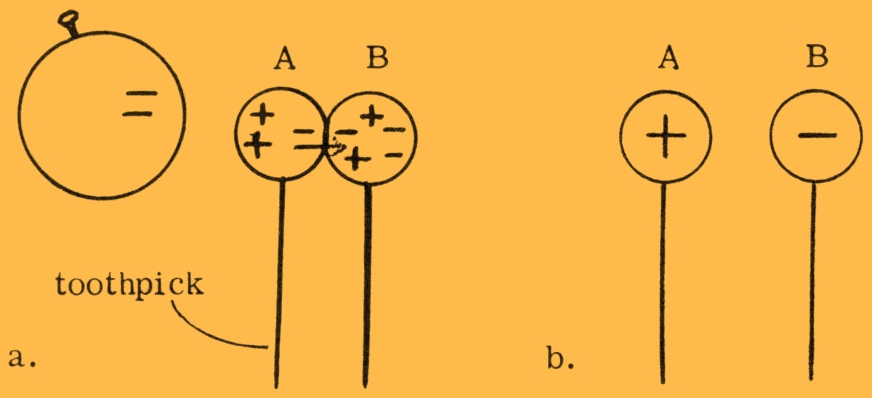


Fig. 12

charging by induction does actually take place.

ELECTROSCOPE

The electroscope is a sensitive instrument used to detect and measure the strength of an electric charge.

To construct your electroscope, first cut a strip from the 1 x 5-inch foil ¼ inches wide by 2 inches long. Obtain a plastic top from a one-pound coffee can or other container of similar size and a wide-mouthed glass jar such as a quart-size mayonnaise jar. The jar should be at least 6 inches deep and 4 inches in diameter—deep and wide enough so that the foil in the completed electroscope will not touch the bottom or sides.

With a straight pin make a hole about ½-inch away from the center of the plastic top, just large enough for the remaining wire in your unit to pass through.

Turn the wire down about ½ inch at one end to form a loop (Fig. 13a). Pass

the other end of the wire through the hole in the plastic top and then bend it at right angles to its length about one inch from the end (Fig. 13b). This projection will hold the aluminum foil so should be horizontal in the completed electroscope.

Smooth out any wrinkles on the aluminum foil strip and fold it in two. Place it on the wire. Now put the complete unit in the jar so that the plastic lid rests securely on the top and neither the wire nor the foil is in contact with the jar at any point (Fig. 13c).

You now have a leaf electroscope.

There are different types of electroscopes designed to fit various requirements, but they are all the same in principle as the simple one you have just constructed.

Experiment 20. Charge one of your balloons by rubbing it with wool. Bring it near the top of the electroscope without touching it. Do the leaves spread apart?

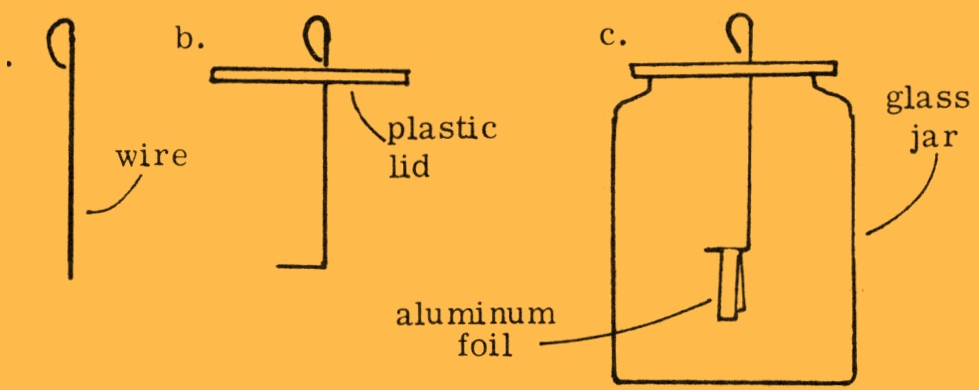


Fig. 13

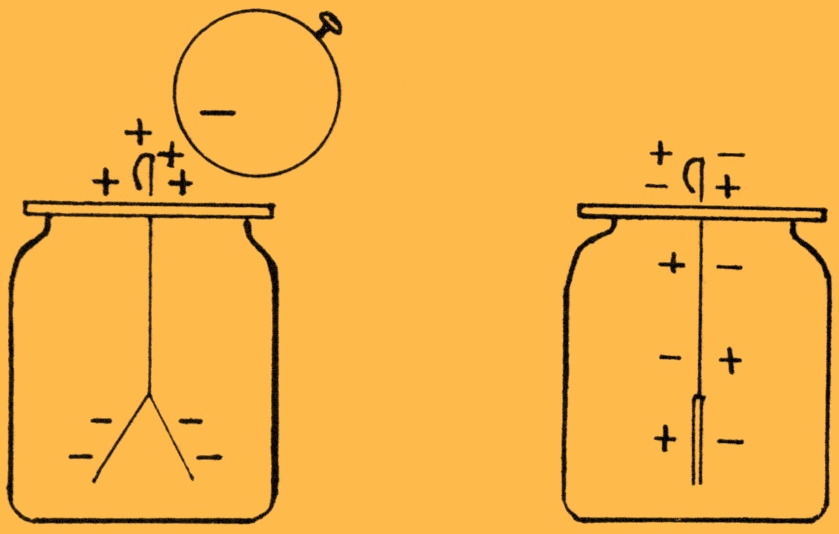


Fig. 14

Don't allow the balloon to come too close to the electroscope or a spark may jump from the balloon to the wire.

Withdraw the balloon. Do the leaves fall back into their original positions? Can you explain why (Fig. 14)?

When the negatively charged balloon was brought near the electroscope the negative electrons were repelled into the aluminum foil leaves, leaving the top positively charged. Since like charges repel, the leaves separated.

When the balloon was removed, the electrons redistributed themselves along the wire and the foil, and the charge disappeared. The neutral aluminum foil dropped back into its former position.

Experiment 21. Touch the electroscope with the charged balloon. Note how the leaves fly apart again.

What happens when the balloon is removed this time? Do the leaves fall back, but not completely? Note that they

remain slightly separated. Why? The electroscope was charged by contact and an excess of electrons remains in the leaves and wire. Why are the leaves repelled farther apart while the balloon is in contact with the electroscope?

Touch and ground the electroscope for the next experiment.

Experiment 22. Charge your glass rod with silk. Bring the charged rod near the electroscope. Note that it also causes the leaves to repel each other. Can you explain what happens? What is the charge on the foil this time?

Experiment 23. Charge the electroscope by contact with your positively charged glass rod so that the leaves remain separated about ½ inch. You may have to recharge the electroscope several times to achieve this. Now bring the negatively charged balloon up to the electroscope without touching it. What

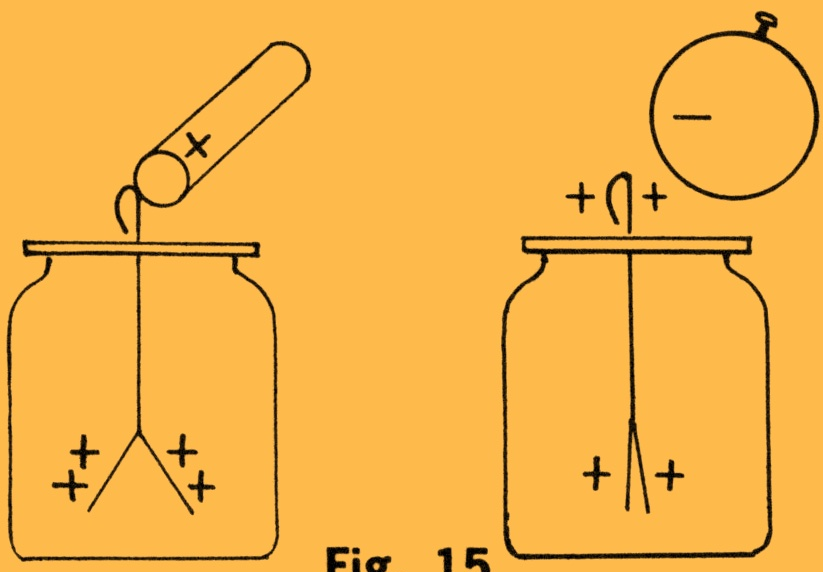


Fig. 15

happens? Do the leaves close up a little (Fig. 15)? Can you explain this occurrence? What happens when the balloon is removed?

Experiment 24. Touch the electroscope to ground it and then bring a negatively charged balloon toward the electroscope, but do not allow the balloon to touch it. While holding the balloon close to the electroscope, touch the wire with your other hand. Note that the leaves fall together. Now remove your finger and

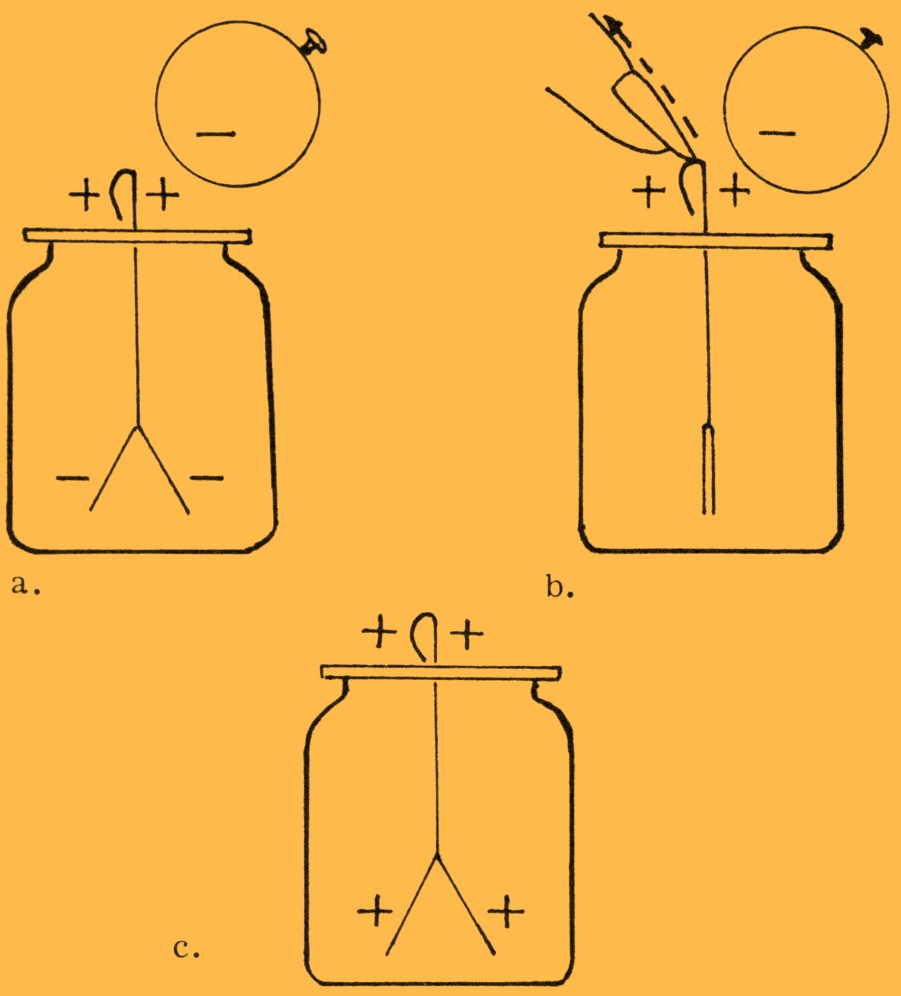


Fig. 16

then the balloon (Fig. 16).

Note that the leaves spread apart again. The electroscope has been charged by induction. Is it negatively or positively charged? How would you test the electroscope to determine the charge?

If a positively charged glass rod were brought near the electroscope now, would the leaves draw together or remain apart?

What happens if you bring a negatively electrified body near the electroscope?

Experiment 25. In a darkened room on a dry day, place a balloon that has been rubbed vigorously with wool close to the electroscope. You will hear a sharp crackle and, if the charge is strong enough, you may see a spark jump from the balloon to the electroscope and a bright glow appear as the leaves spread apart.

Can you explain these results from observations in your previous experiments?

JUST FOR FUN

Experiment 26. Obtain another plastic coffee can cover or similar plastic and a shallow tin about 4 inches in diameter and an inch or 1½ inches deep. A shallow tunafish can will be suitable if it is wide enough.

Cut out from wax paper or other lightweight paper tiny figures or star

shapes. The figures should be shorter than the height of the can and fairly narrow. Make about six or seven of these and place them in the can. Cover the can with the plastic lid.

Rub the plastic back and forth with your hand fairly vigorously to create static electricity. The figures will soon begin to dance up and down like jumping jacks. Can you explain why the figures behave as they do?

From your various experiments you now have some understanding of the principles involved in electrostatics. Many useful devices have been designed using electrostatics, such as in electrostatic printing, in the various substances used to neutralize static electricity in industry and in the home, electrostatic precipitators for cleaning air and electrostatic machines such as the electrophorus to supply electricity for specific purposes.

If you wish to study the subject further, the references below will be helpful.

Most elementary physics textbooks.

Physics, Vol. II: Electricity, Magnetism and Optics by Arnold L. Reimann, Barnes and Noble, Inc. New York (1971).

Source Book of Science Experiments for Elementary Grades by Steven J. Mark, Vantage Press, New York (1971).

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